

Telescope (HST), and the Infrared Space Observatory (ISO, a European space telescope with NASA collaboration), as well as from numerous ground-based radio and optical telescopes. In addition, they have been used to determine requirements for future missions such as the Stratospheric Observatory for

Infrared Astronomy (SOFIA) and the Space Infrared Telescope Facility (SIRTF).

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The Formation and Dynamics of Planetary Systems

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Progress was made in FY00 in numerous areas bearing on the overall problem of the formation and evolution of planetary systems. Specific topics of research have ranged from the earliest stages of star formation through the long-term fate of the Earth, and they are described in four peer-reviewed research papers.

In the present-day solar system, the sun contains 99.9% of the mass, whereas the planets contain the bulk of the system angular momentum. The clouds of gas and dust that collapse to form star-planet systems, however, are essentially in uniform rotation. One of the major unsolved puzzles in the theory of star and planet formation thus involves the detailed mechanism by which mass is transported inward onto the protostar while angular momentum is simultaneously pushed outward. It is believed that spiral gravitational instabilities play a key role in eliciting angular momentum transport, but a full description of how spirals grow and operate on a global scale (that is, throughout the entire protoplanetary disk) is not understood. Considerable theoretical progress was made in this area by performing a stability analysis of idealized singular isothermal disks. This research, carried out and published in collaboration with researchers at the University of California at Berkeley, Arcetri (Italy), and UNAM (Mexico), has clearly explained the role of the corotation

amplifier in allowing spiral waves to grow. This in turn gives us a clearer theoretical picture of the very earliest stages of star and planet formation.

A second line of inquiry has developed a way to constrain the conditions under which our own solar system formed. The outer giant planets in our solar system all have nearly coplanar, circular orbits. This orderly configuration indicates that the sun and the planets have always existed in relative isolation. If another stellar system had passed within several hundred astronomical units of the sun, gravitational perturbations would have scattered the outer planets (particularly Neptune) into highly eccentric, inclined orbits. An extensive set of Monte Carlo star-planet scattering calculations has shown that the solar system likely formed in an aggregate containing fewer than 1500 stars, and thus was not born in a dense stellar cluster (resembling, say, the Trapezium region in Orion). Primitive meteorites, however, contain daughter products of extinct radioactive elements that have half-lives of one million years or less. In order to explain the presence of such short-lived isotopes in meteorites, it has been proposed that either (1) the presolar nebula was enriched by a nearby supernova explosion, or alternately that (2) x-ray flares associated with the nascent sun were able to create radioactive atoms via

processes such as spallation. The new research strongly favors scenario (2), because the presence of a nearby supernova would imply that the sun formed in a very massive aggregate of stars, and this possibility is effectively ruled out by the Monte Carlo calculations.

A third focus of the research effort examined the emerging correlation between high stellar metallicity and the detected presence of an extrasolar planet. Now that more than 70 extrasolar planets have been found, it is possible to evaluate the emergence of statistical trends. An analysis of volume-limited samples of stars in the solar neighborhood demonstrated that stars with metal content >50% higher than solar are 10 times more likely to harbor a

short-period planet than the average star in the solar neighborhood. This finding can be exploited to find extrasolar planets with less effort, thus saving large amounts of time on instruments such as the Keck Telescope. A catalog of 200 highly metal-rich stars was compiled, and within 6 months, 5 planets have been detected in this catalog. Two were found by the Marcy group, two were found by Swiss researchers, and one was found by Ames researchers (HD 20675b, to be confirmed and announced in late 2001).

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Stability of Upsilon Andromedae's Planetary System

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The objectives of this project are to study the dynamical properties of planetary systems that are consistent with the observational data on the three-planet system orbiting the nearby main sequence star Upsilon Andromedae. Results show that systems with the planetary masses and orbital parameters that provide the best fit to stellar radial velocity observations made at Lick Observatory through either February 2000 or July 2000 are substantially more stable than systems with the parameters originally announced in April 1999. Simulations using the February 2000 parameters are stable for planetary masses as much as four times as large as the observational lower bounds (which are obtained by assuming that

the solar system lies in the orbital plane of the Upsilon Andromedae planetary system). In relatively stable systems, test particles (which can be thought of as representing asteroids or Earth-like planets that are too small to have been detected to date) can survive for long times between the inner and middle planets as well as several astronomical units or more exterior to the outer planet, but no stable orbits were found between the middle and outer planets.

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